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(54) **INSPECTION SYSTEM FOR OLED DISPLAY PANELS**

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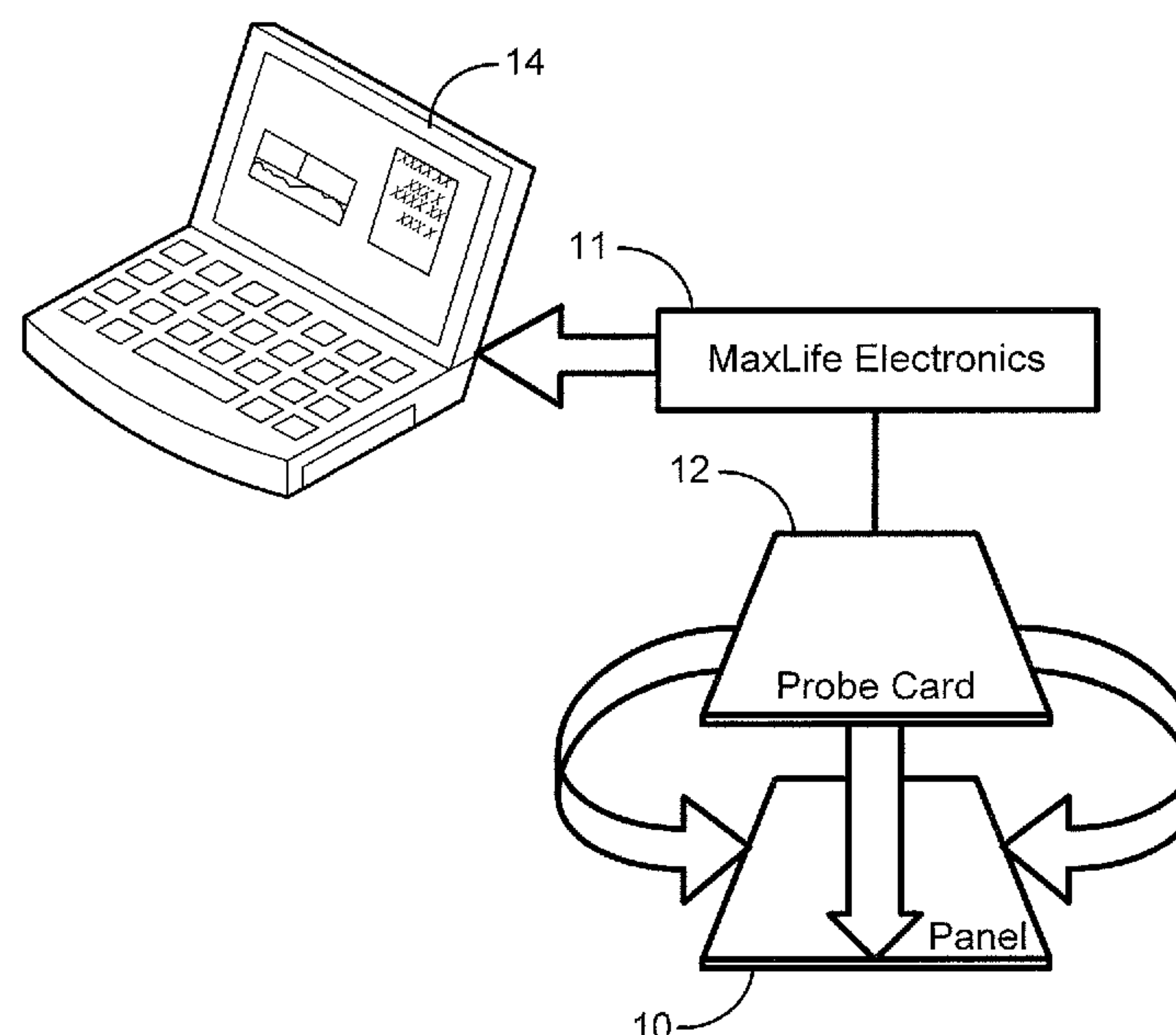
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(57) **ABSTRACT**

A system for inspecting at least a portion of a display panel having thin film transistors (TFTs) and light emitting devices (OLEDs), during or immediately following fabrication, so that adjustments can be made to the fabrication procedures to avoid defects and non-uniformities. The system provides bonding pads connected to signal lines on at least portions of the display panel, and probe pads along selected edges of the display panel. The probe pads are coupled to the bonding pads through a plurality of multiplexers so that the number of probe pads is smaller than the number of bonding pads.

12 Claims, 4 Drawing Sheets



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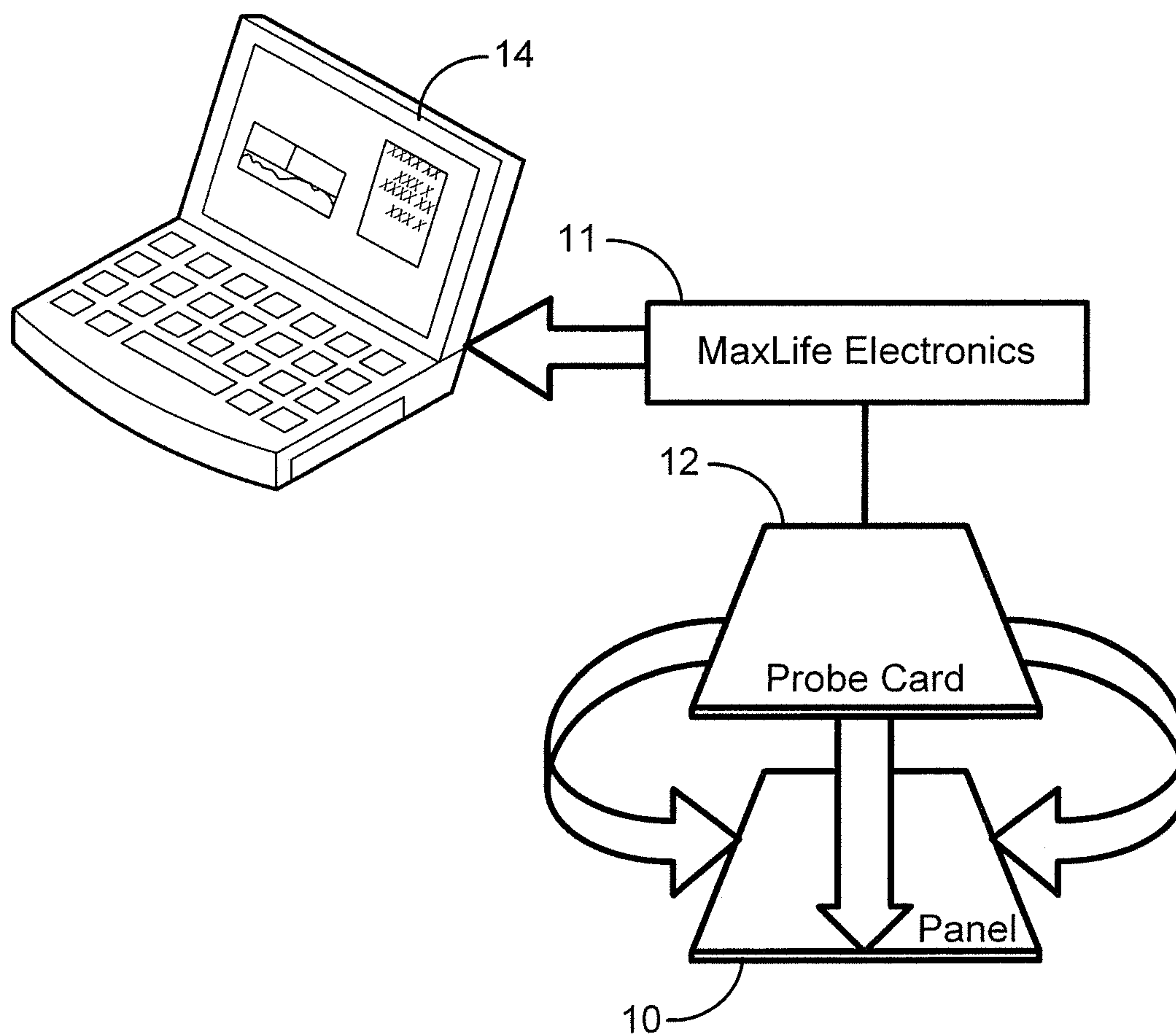


FIG. 1

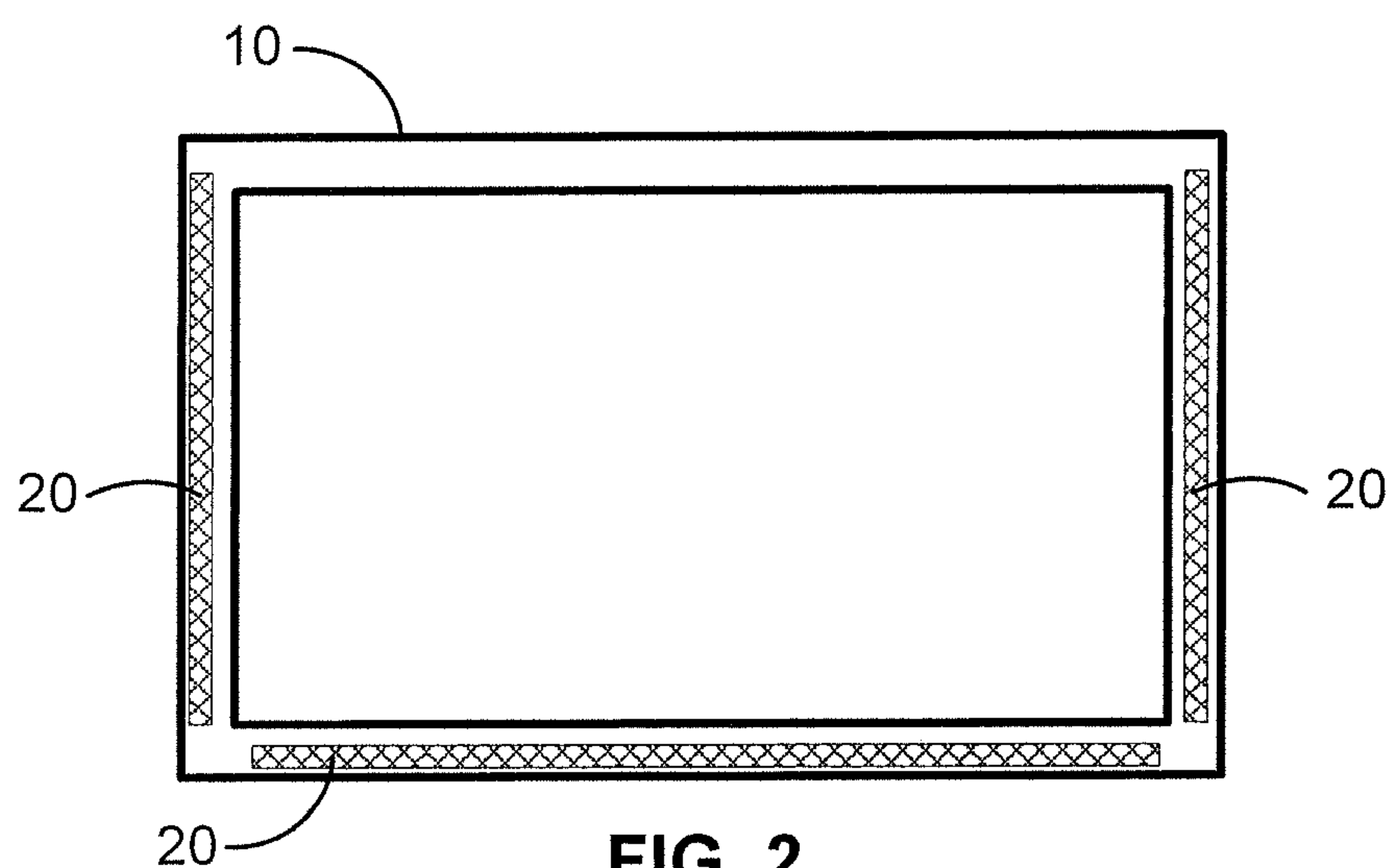


FIG. 2

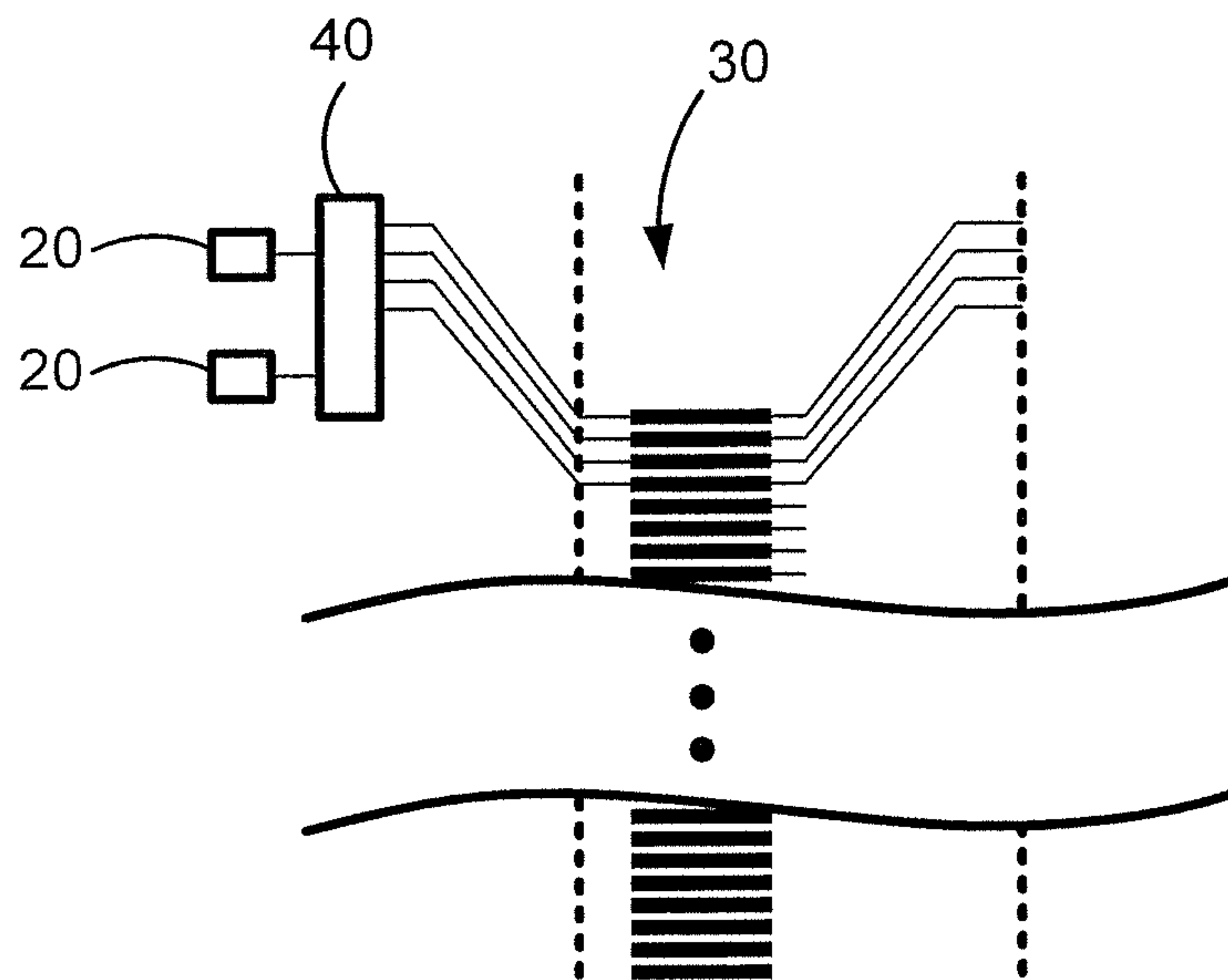


FIG. 3

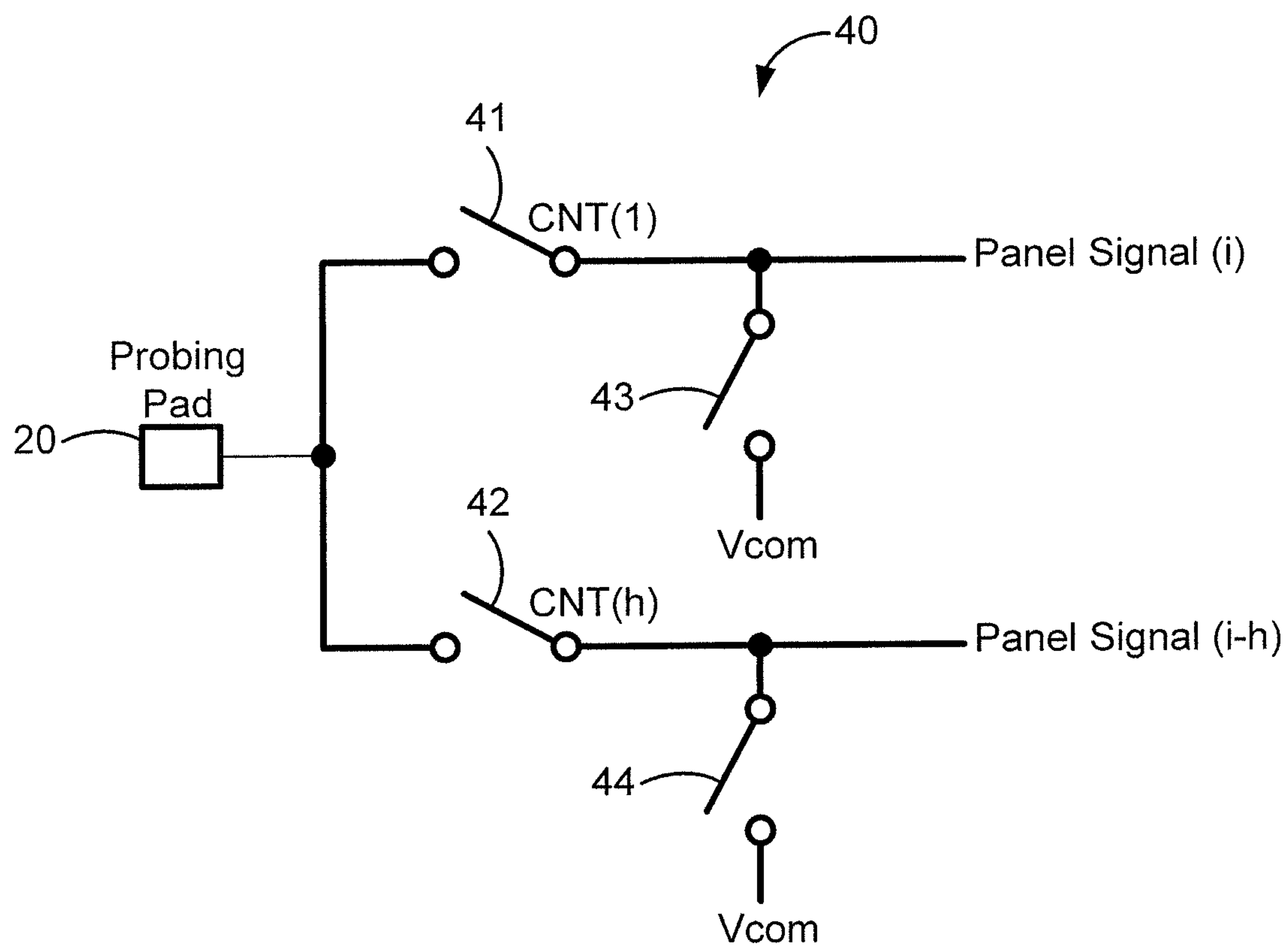
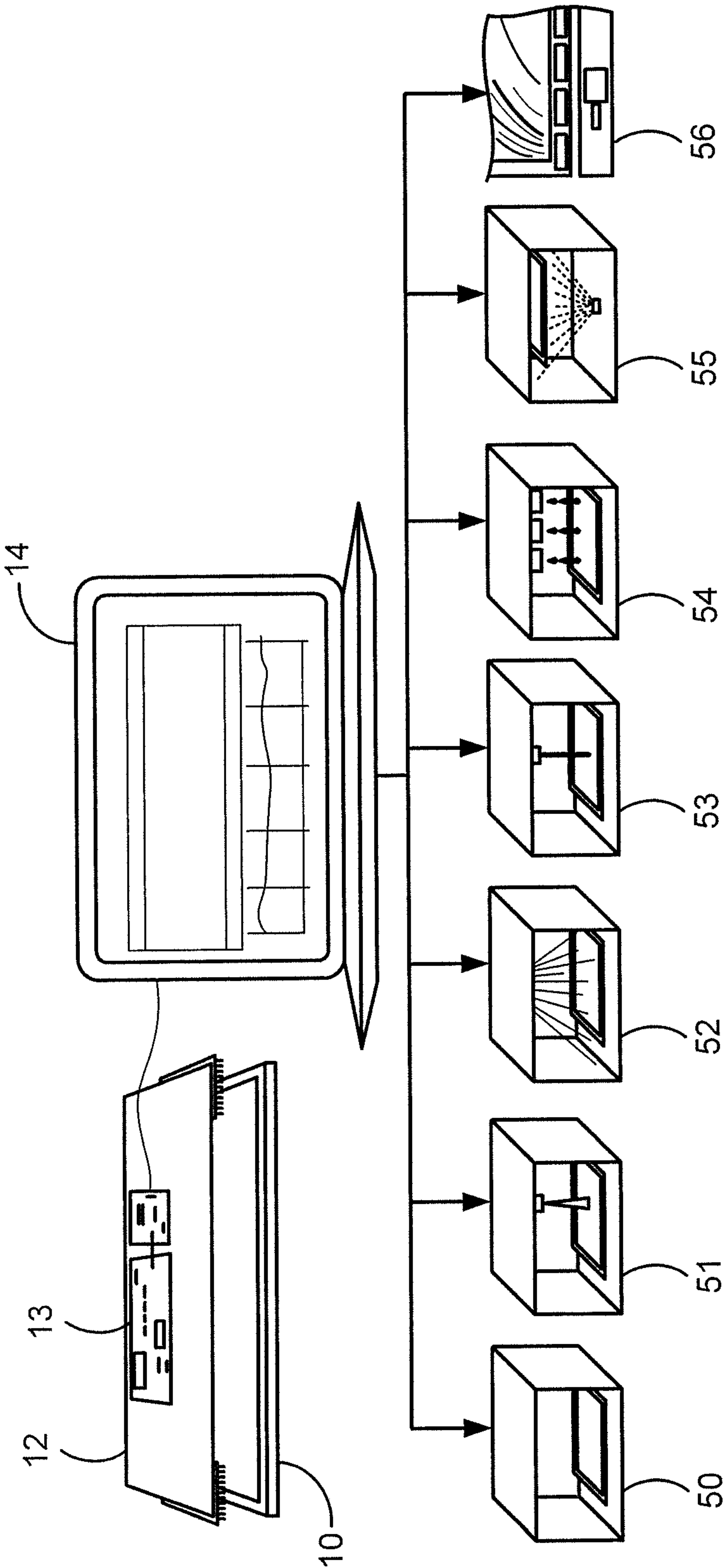


FIG. 4



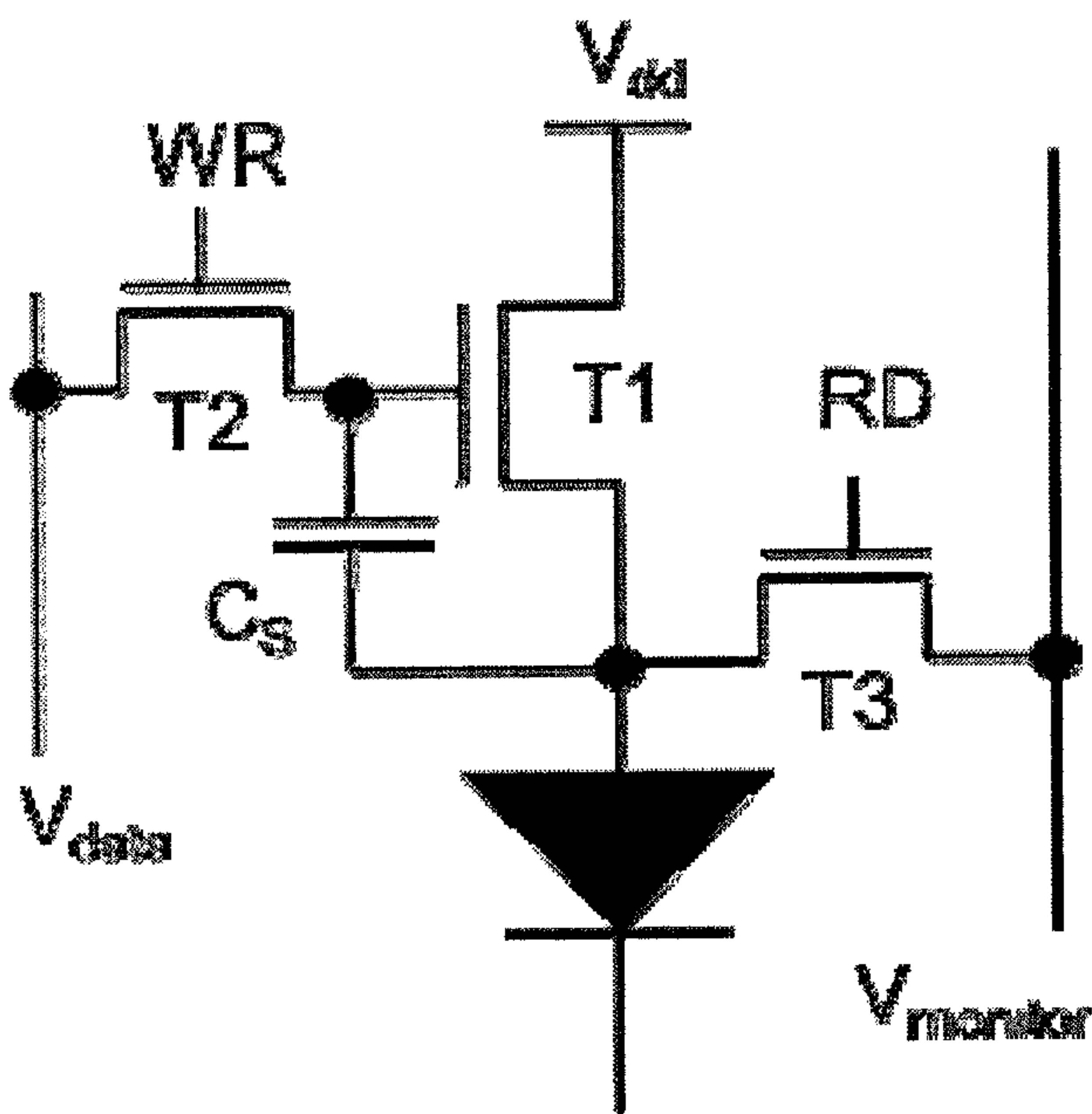


FIG. 6

INSPECTION SYSTEM FOR OLED DISPLAY PANELS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/861,614, filed Aug. 2, 2013, and U.S. Provisional Application No. 61/814,580, filed Apr. 22, 2013, both of which are hereby incorporated by reference herein in their entireties.

FIELD OF THE INVENTION

The present invention relates generally to OLED displays and, more particularly, to inspection systems for detecting defects and non-uniformities in displays such as active matrix organic light emitting diode displays.

BACKGROUND

Display panels can be created from an array of light emitting devices each controlled by individual circuits (i.e., pixel circuits) having transistors for selectively controlling the circuits to be programmed with display information and to cause the light emitting devices to emit light according to the display information. Thin film transistors ("TFTs") fabricated on a substrate can be incorporated into such display panels. Both OLEDs and TFTs can demonstrate non-uniform behavior across display panels due to production problems. Such problems can be corrected if the defects and non-uniformities can be identified at the time the panels are produced, e.g., during or immediately following fabrication.

SUMMARY

A system is provided for inspecting at least a portion of a display panel having thin film transistors (TFTs) and light emitting devices (OLEDs), during or immediately following fabrication, so that adjustments can be made to the fabrication procedures to avoid defects and non-uniformities. The system provides bonding pads connected to signal lines on at least portions of the display panel, and probe pads along selected edges of the display panel. The probe pads are coupled to the bonding pads through a plurality of multiplexers so that the number of probe pads is smaller than the number of bonding pads.

The foregoing and additional aspects and embodiments of the present invention will be apparent to those of ordinary skill in the art in view of the detailed description of various embodiments and/or aspects, which is made with reference to the drawings, a brief description of which is provided next.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings.

FIG. 1 is a diagrammatic perspective illustration of a display panel adapted to receive a probe card.

FIG. 2 is a diagrammatic front elevation of the display panel shown in FIG. 1, showing the locations of probe pads for receiving probe cards.

FIG. 3 is a diagram of a pair of probe pads connected to a multiplexer used to supply probe signals to the probe pads.

FIG. 4 is a schematic circuit diagram of one of the probe pads illustrated in FIG. 3 connected to receive the display signals.

FIG. 5 is a diagrammatic illustration of an inspection system for taking measurements of an AMOLED panel, and various corrective actions that can be taken to fix defects identified by analysis of the measurements.

FIG. 6 is a schematic circuit diagram of a pixel circuit having a signal WR.

While the invention is susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and will be described in detail herein. It should be understood, however, that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

FIG. 1 illustrates a system for inspecting an OLED display panel 10 at one or more stages of the fabrication of the panel 10 (e.g., a TFT backplane, a fully fabricated panel, or a fully completed and sealed panel). The display panel 10 is coupled to a computer 14 through measurement electronics 11 and a probe card 12, to provide the capability of testing and verifying the panel at each processing step. For example, after finishing the TFT backplane, the probe card system can be used to measure the performance of the TFT backplane by itself. If the TFT backplane is acceptable, then the panel 10 is passed to the next step which can be the OLED deposition stage. After the OLED deposition is completed, the panel 10 can be measured for proper OLED deposition before sealing. After sealing, the panel 10 can be measured again before it is sent to an assembly process.

As can be seen in FIG. 2, the illustrative display panel 10 has probe pads 20 formed along three of the four edges of the panel. Probe pads can also be formed inside the panel, preferably before the OLED deposition stage. The probe pads 20 are used to supply test signals to the numerous pixel circuits on the display panel 10, via bonding pads 30 formed at the outer ends of the various signal lines leading to the pixel circuits.

FIG. 3 illustrates the connection of the probe pads 20 to the bonding pads 30 through a multiplexer (MUX) 40, to reduce the required number of probe pads, which in turn permits the pad pitch to be increased. To ensure that the other signals connected to the probe pads 20 are biased properly, the MUX 40 needs to be capable of connecting each probe pad 20 to a common signal (Vcom) for each group of signals (e.g., source signals, gate signals, etc.).

FIG. 4 illustrates a MUX 40 with common signal control and two or more panels signals for each probe pad 20. FIG. 4 illustrates h panel signals connected to one probe pad 20, thus requiring 2 h controlling signals for connection to the probe pads 20 or connection to the common signals. The connections of the panel signals to the probe pad 20 are controlled by first switches 41 and 42, and the connections of the common signals Vcom to the panel signal lines are controlled by second switches 43 and 44.

The proper pad pitch for full panel probing is typically about 150 μm . As illustrated by the data in Table 1, the pad pitch for most conventional configurations meets the minimum pad pitch requirements. However, using multiplexing

ratios of 2:1 or greater permits the pad pitch to be increased, resulting in much simpler probe cards, as also illustrated by the data in Table 1:

TABLE 1

Pad pitch for different display sizes and resolutions.				
Panel	MUX	Gate Pad Pitch (μm)	Source Pad Pitch (μm)	EIC Pad Pitch (μm)
55" HD	1:1	295	330	330
55" HD	2:1	592	661	661
55" HD	8:1	2370	2645	2645
55" UD	1:1	148	165	165
55" UD	2:1	295	330	330
55" UD	8:1	1185	1132	1132
78" UD	1:1	222	222	222
78" UD	2:1	444	445	445
78" UD	8:1	1777	1781	1781

As depicted in FIG. 5, an electronic measuring system 13 mounted on the probe card 12 can measure the electrical characteristics of every TFT and every OLED device in a display panel 10 and identify defects and non-uniformities. This data is supplied to a GUI 14, where the data can be used to fine-tune every process step, to achieve higher yields, faster process ramp-up, and lower line monitoring costs. Examples of the various process steps that can be fine tuned are illustrated in FIG. 5, namely, a sputtering and PECVD module 50, a process annealing module 51, a patterning module 52, a laser repair module 53, an inkjet printing module 54 and an evaporation module 55. The end result is a complete display panel 56.

The circuitry depicted in FIG. 5 takes data from the measurement electronics 13, analyzes that data, and displays it in a wide variety of reports, tables, and pictures. Some of the views are described in the following table:

View	Description
TFT Absolute LUT	View the absolute measurement replacement values for each pixel on the panel.
TFT Filtered LUT	View the filtered replacement values used to calculate delta values.
TFT Base LUT	View the factory shipment values of the panel to determine how much the pixels have aged (baseline).
TFT Delta LUT	View the difference between the current average measured value and the baseline values (used to determine compensation).
TFT Histogram LUT	View the number of times a pixel has been measured since the last time the histogram was reset. This lookup table is primarily used for priority scan algorithm.
TFT Pixel State LUT	View either the current state of the measurement state machine or the last comparison values for each pixel.
TFT Region Priority	Show the priority of each region in the priority scan algorithm.
OLED Absolute LUT	View the absolute measurement replacement values for each pixel on the panel OLED layer.
OLED Filtered LUT	View the filtered replacement values used to calculate delta values.
OLED Base LUT	View the factory shipment values of the panel to determine how much the pixels have aged (baseline).
OLED Histogram	View the number of times a pixel has been measured since the last time the histogram was reset.
OLED Pixel State	View either the current state of the measurement state machine or the last comparison values for each pixel.
OLED Region Priority	Show the priority of each region in the priority scan algorithm.

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View	Description
5 Dead Pixels LUT	Show which pixels were either dead at point of manufacture or have since been determined to be unresponsive. Note that dead pixels are not compensated.
Combine Delta LUT	The combined TFT and OLED delta values used to determine the final compensation.
10 Scratch LUT	A temporary LUT View to allow users to manipulate the data without making modifications to the system tables or to simply “backup” a table.
Statistics	Reports the performance statistics and the current frame rate. Use these statistics to compare the time required to process and display the current data in MaxLife Viewer vs. the time it would actually take if the display was not required.
15 Pixel Trends	View the pixel state to determine if there are unsettled pixels and view comparative levels. Allows you to obtain a visual representation of uncertainty zones and look at specific defective pixels. Use this option to obtain active measurements over time; determine how many times a pixel was measured before it settled. Select a LUT table, then analyze the uniformity.
20 Uniformity Report Offset	
25 Characterization	Plots the V-to-I voltage DAC code to the probability of a comparator result flip.
Hardware Configuration	View the current hardware configuration parameters.
30 Display Controls	Adds the Display Controls to the bottom of the current tab. These options allow you to set the frame refresh rate in frames per second. Drag the slider to the left or right to speed up or slow down the refresh rate. Slower speeds are more visible to the naked eye.
CLI View	Issues commands from MaxLife Viewer to the system.

A wide variety of different circuitry and algorithms may be used for extracting measurements of different parameters from the display panel at different stages of its fabrication, such as the extraction systems described in U.S. patent application Ser. No. 13/835,124 filed Mar. 15, 2013 and entitled “Systems and Methods for Extrraction of Threshold and Mobility Parameters in AMOLED Displays,” which is incorporated by reference herein in its entirety.

The inspection system can identify many potential defects and problems (e.g., with sputtering and PECVD steps, that can be used to identify the likely cause of the defect or problem so that the fabricating process can be immediately fine-tuned to correct the problem). Examples of such issues and their likely causes are the following:

Issue identified by MaxLife™ inspection system		Likely cause
55 Line defect (open circuit on metal lines)		Particle defect during deposition, poor adhesion, contaminated substrate and poor step coverage.
High resistance or non-uniform resistance on metal lines		Non-uniform sputtering process, contaminated sputter gas or process chamber.
60 Non-uniform TFT contact resistance		Problem with n+ layer PECVD step, incomplete via etch or photoresist stripping process.
Vt or mobility of TFTs out of specification		Problem with a-Si layer PECVD step (contamination during deposition, process parameter drift or film stress)
65 Open TFT channel		Problem with a-Si or n+ layer deposition (particle contamination during deposition/contaminated substrate)

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Issue identified by MaxLife™ inspection system	Likely cause
Gate shorted to fixed voltage	Incomplete metal patterning and/or damaged dielectric layers from particles or ESD
Source or gate shorted to drain	Damaged dielectric layers (pinholes) from particles or ESD
Open or high resistance contacts	Incomplete via etching.
Out of spec capacitance	Non-uniform dielectric layer deposition or drift in deposition process parameters.
Line defect (crossover short)	Pinhole in the dielectric layers from particles or ESD

For defects that cannot be directly identified by a single measurement of the inspection system, the first measurement can reveal that a problem exists, and specify additional tests that will conclusively identify the exact defect. One example is the identification of line defects, which can be detected by any of the following procedures:

1. Measuring the current of different lines: if the current is higher than a threshold, the pixel is shorted.
2. Applying pulse to measure the charge transfer: if the amount of charge transfer is smaller than a threshold, the line is open.
3. For a signal with connection to DC current (e.g., Vdd and Vmonitor), the current can be measured to detect the open defect

Defects in the thin film transistors (TFTs) can also be detected. For example, in the situation where the pixel circuit in FIG. 6 has a signal WR measured as high (while Vdata=high, and also while Vdata=low, and Vdd=high), an additional test needs to be performed. Table 1 shows the different conditions and what the results mean.

To detect problems with process annealing, the exact Vt and mobility of each TFT can be used to adjust process annealing parameters, as follows:

Issue identified by MaxLife™ inspection system	Likely cause
Vt and/or mobility of TFTs is higher or lower than specification	Laser power drift
Small scale non-uniformity of Vt and/or mobility of TFTs	Intermittent laser power output
Large scale non-uniformity of Vt and/or mobility of TFTs	Laser repeatability

The number and types of defects can be used to identify problems in patterning (particles, under/over exposure, etc.), as follows:

Issue identified by MaxLife™ inspection system	Likely cause
High-resistance metal lines	Pattern definition or metal etch process. Poor line width control.
Open or high resistance contacts	Poor via pattern definition/photoresist residue
Gate shorted to fixed voltage	Pinholes in the dielectric layers.
Abnormal capacitance or resistance in corners of panel	Mask alignment error (rotation), photoresist thickness non-uniformity.
Large scale capacitance or resistance, non-uniformity	Pattern alignment error or exposure power fluctuation.

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Issue identified by MaxLife™ inspection system	Likely cause
Adjacent metal lines shorted	Particles in photoresist/pattern definition.
Pattern stitching defects	Stepper alignment failure
Repetitive defect	Exposure masks damage or contaminated.

The defect location and defect type can be used to pinpoint areas suitable for laser repair (removing material) or ion beam deposition (adding material), as follows:

Issue identified by MaxLife™ inspection system	Repair Step
Gate shorted to fixed voltage	Give exact pixel location to laser repair system
Short on metal lines	Identify the metal lines that are shorted.
Open circuit on metal lines	Identify the metal lines that are open.
Open or high resistance TFT contacts	Quickly identify the number and location of the defective pixels.

The uniformity data can also be used to continuously calibrate each print head used for inkjet printing, in real-time. The system knows which print head was used to print each pixel, and thus problems with individual print heads can be detected. The print head used to print those pixels can then be immediately adjusted, as follows.

Issue identified by MaxLife™ inspection system	Likely cause
Dead pixels	Printhead occasionally putting down too little material, causing shorts
Stuck-on pixel	Printhead occasionally putting down too little material
High-resistance pixels	The printhead printing those pixels may be putting down too much material
Uniformity of OLED's voltage is poor	Flow control of printhead malfunctioning

The exact failure mode of every OLED device can be used to tune the evaporation process, as follows:

Issue identified by MaxLife™ inspection system	Likely cause
All pixels from one printhead are too high (or too low) resistance	Problem with calibration of printhead
Short-circuit OLED	Too little organic material being deposited, causing shorts
High-resistance pixels	Too much organic material being deposited
OLED voltage too high	Too much organic material being deposited
Long-range Uniformity of OLED's voltage is poor	Problem with substrate rotation or evaporator too close to substrate
Short-range uniformity of OLED's voltage is poor	Problem with thermal evaporation temperature control
Open-circuit OLED	Particles during evaporation
Short to cathode or anode	Particles during evaporation
Partial short (low resistance)	Too little organic material being deposited

The electrical characteristics (collected during TFT and OLED inspection) can be loaded into a lookup table, and used to correct for all TFT and OLED non-uniformities.

Additional defects can be identified once both the OLEDs and TFTs have been deposited. The first measurement can identify that a problem exists, and specify additional tests that will conclusively identify the exact defect.

If test samples are created around the periphery of the panel, then more details about the global process parameters can be extracted. Typically this is done by cutting off the test samples from a small percentage of displays and putting them in a separate characterization system. However, with the present inspection system, this can be done as part of panel characterization, for every panel, as follows:

Metal lines can be created and resistance measured. This can test both metal deposition steps and etching.

Semiconductor layers to be annealed can have their characteristics and uniformity tested.

Structures can be used at different locations around the panel to test alignment.

OLED structures can be used to test evaporation and inkjet printing steps.

While particular embodiments and applications of the present invention have been illustrated and described, it is to be understood that the invention is not limited to the precise construction and compositions disclosed herein and that various modifications, changes, and variations can be apparent from the foregoing descriptions without departing from the spirit and scope of the invention as defined in the appended claims.

The invention claimed is:

1. A method of fabricating a display panel, said method comprising:

fabricating a thin film transistor (TFT) backplane for the display panel, including:

forming a plurality of pixel circuits that include TFTs; and

prior to including any organic light emitting diodes (OLEDs) on the TFT backplane:

forming bonding pads connected to respective signal lines on at least portions of the TFT backplane;

forming probe pads along selected edges of said portions of the TFT backplane;

forming common signal lines in said backplane; and

forming a plurality of multiplexers within said TFT backplane for coupling said probe pads to said bonding pads and for coupling said common signal

lines to said probe pads, the number of probe pads less than the number of bonding pads, in

which said plurality of multiplexers are configured to controllably separately connect each of said probe pads to each of at least two of said bonding

pads, each multiplexer including first switches providing connections of multiple panel signal

lines via respective bonding pads to a probe pad, and second switches providing connections of said

common signal lines to panel signal lines via respective bonding pads;

engaging said probe pads of said TFT backplane with measurement electronics prior to including any OLEDs on the TFT backplane;

supplying test signals from said measurement electronics via said probe pads and said plurality of multiplexers to test said TFTs of the TFT backplane prior to including

any OLEDs on the TFT backplane steering common

signals, received by said multiplexers over said common signal lines, to said panel signal lines via respective bonding pads; and

forming OLEDs on the TFT backplane within said pixel circuits, subsequent to supplying said test signals.

2. The method of claim 1 in which a computer is coupled to said measurement electronics.

3. The method of claim 1 in which said probe pads are formed along a plurality of edges of said TFT backplane.

4. The method of claim 1 in which said display panel is an AMOLED display panel.

5. The method of claim 1 in which each of said multiplexers is capable of connecting each probe pad to common signals (Vcom) for multiple groups of signals.

6. The method of claim 1 in which said testing of said TFTs includes measuring the electrical characteristics of the TFTs of the pixel circuits of the TFT backplane.

7. A thin film transistor (TFT) backplane for a display panel, the TFT backplane comprising:

a plurality of pixel circuits that include thin film transistors (TFTs) and do not include any organic light emitting devices (OLEDs),

multiple signal lines on portions of the TFT backplane, multiple respective bonding pads connected to said signal lines,

common signal lines;

multiple probe pads positioned along selected edges of the portions of the display panel that have said signal lines, for engagement with measurement electronics for providing test signals to test said TFTs of the TFT backplane prior to OLED deposition, and

multiple multiplexers for coupling said probe pads to said bonding pads and for coupling said common signal lines to said bonding pads, each multiplexer including first switches providing connections of multiple panel signal lines via respective bonding pads to a probe pad, and second switches providing connections of said common signal lines to panel signal lines via respective bonding pads, and each multiplexer configured to controllably separately connect each of said probe pads to each of at least two of said bonding pads during said testing of said TFTs of the TFT backplane prior to OLED deposition and configured to controllably steer common signals, received by said multiplexers over said common signal lines, to said panel signal lines via respective bonding pads.

8. The TFT backplane of claim 7 which includes a computer coupled to said measurement electronics.

9. The TFT backplane of claim 7 in which said probe pads are formed along a plurality of edges of said TFT backplane.

10. The TFT backplane of claim 7 in which said display panel is an AMOLED display panel.

11. The TFT backplane of claim 7 in which each of said multiplexers is capable of connecting each probe pad to common signals (Vcom) for multiple groups of signals.

12. The TFT backplane of claim 7 which includes a processor configured to measure the electrical characteristics of the TFTs of the pixel circuits of the TFT backplane, and to identify defects and non-uniformities in the TFT backplane based on the measured electrical characteristics.